National Science Foundation

Materials and the Rectenna

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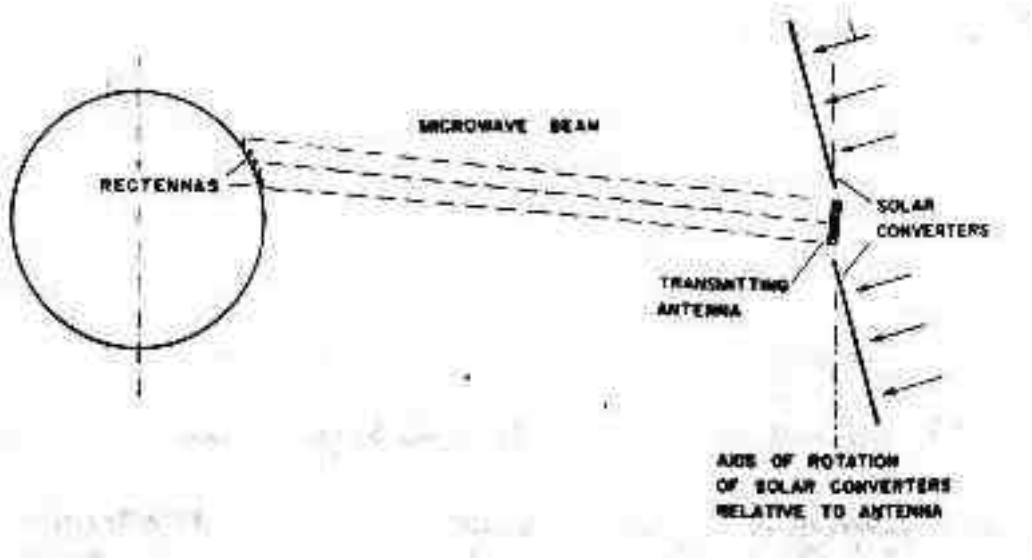
SOLAR POWER STATION



Power = 10^7 KW
10,000 Amplitrons
Collecting aperture 10 x 10 km
Transmitting aperture 0.5 x 0.5 km
S-Band

Diagram of Satellite Solar Power Station

G. Goubau
Journal of Microwave Power, 1970

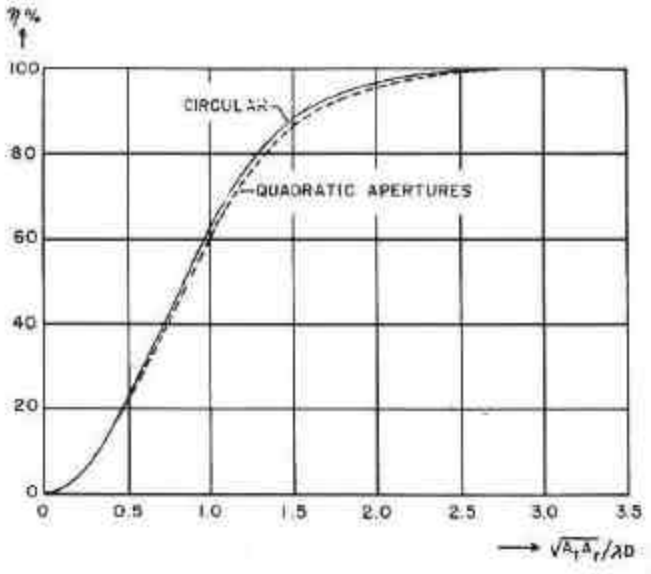
TRANSMISSION EFFICIENCY

A_t = area of transmitting aperture

A_r = area of receiving aperture

D = Transmission path length

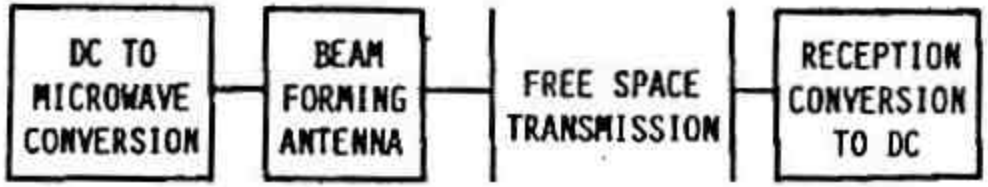
ι = wavelength



Optimum Transmission Efficiency

G. Goubau
Journal of Microwave Power, 1970

Beamed Microwave Power System



MAXIMUM POSSIBLE DC TO DC EFFICIENCY --- 76%

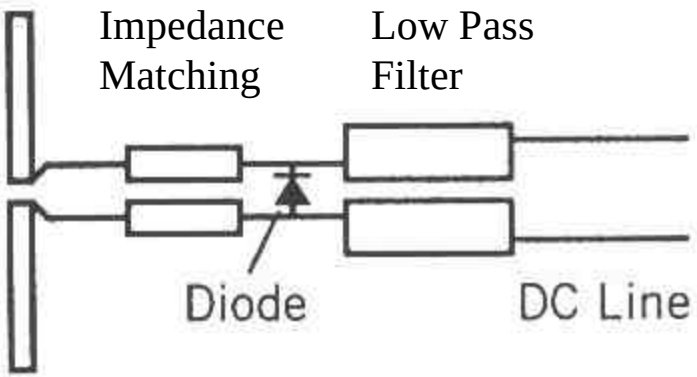
EXPERIMENTAL DC TO DC EFFICIENCY --- 54%

Note: These Efficiencies apprea Optimistic, Especially for the;
"Reception Conversion to DC"

W. C. Brown, et.al, IEEE, 1992

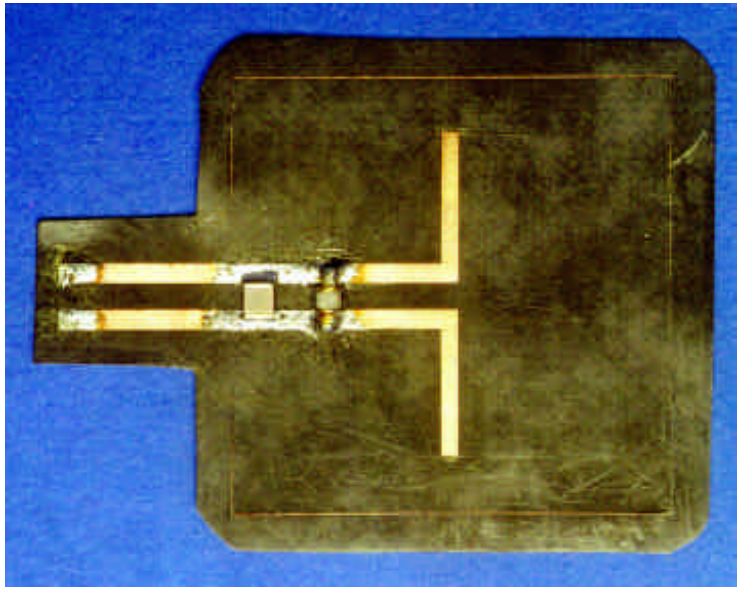
Typical Rectenna Element

Dipole Antenna



Rectenna Photo

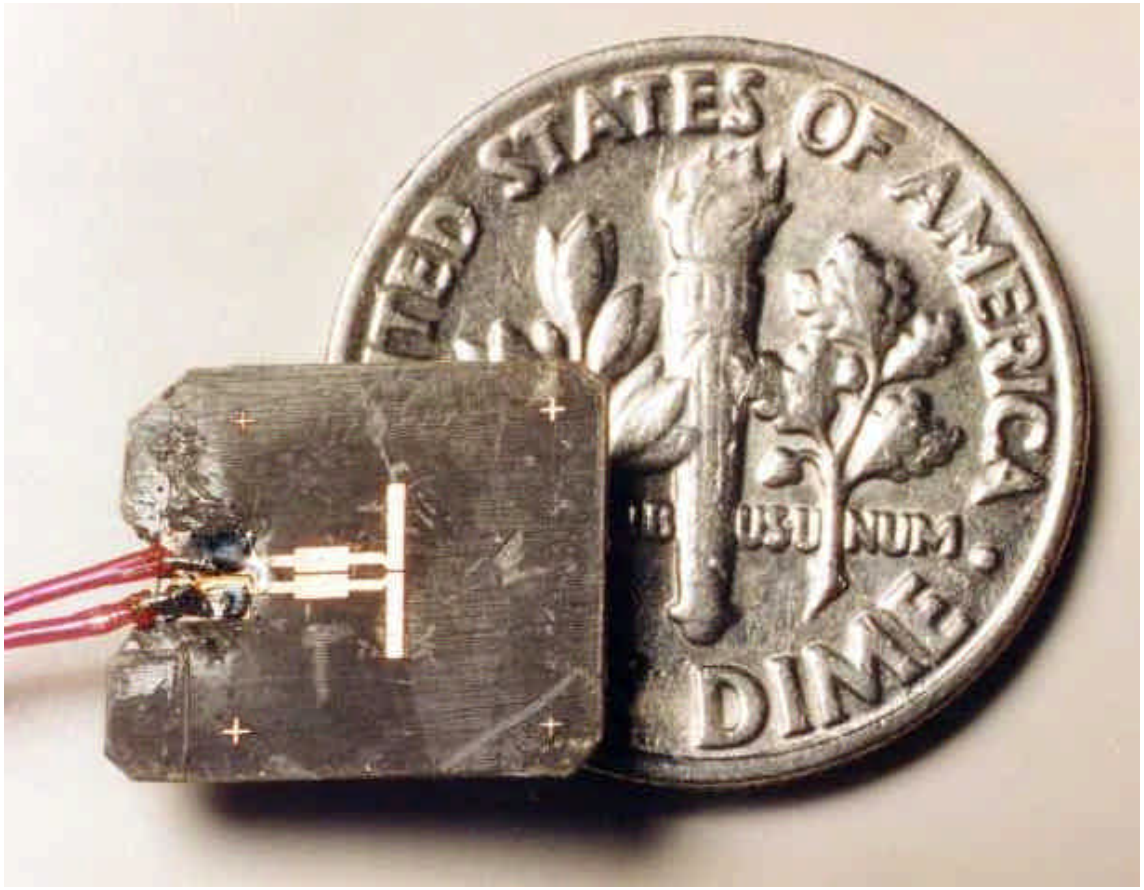
Frequency = 5.8 GHz



Kai Chang, et.al., IEEE-MTT, 1998

Rectenna Photo

Frequency = 35 GHz



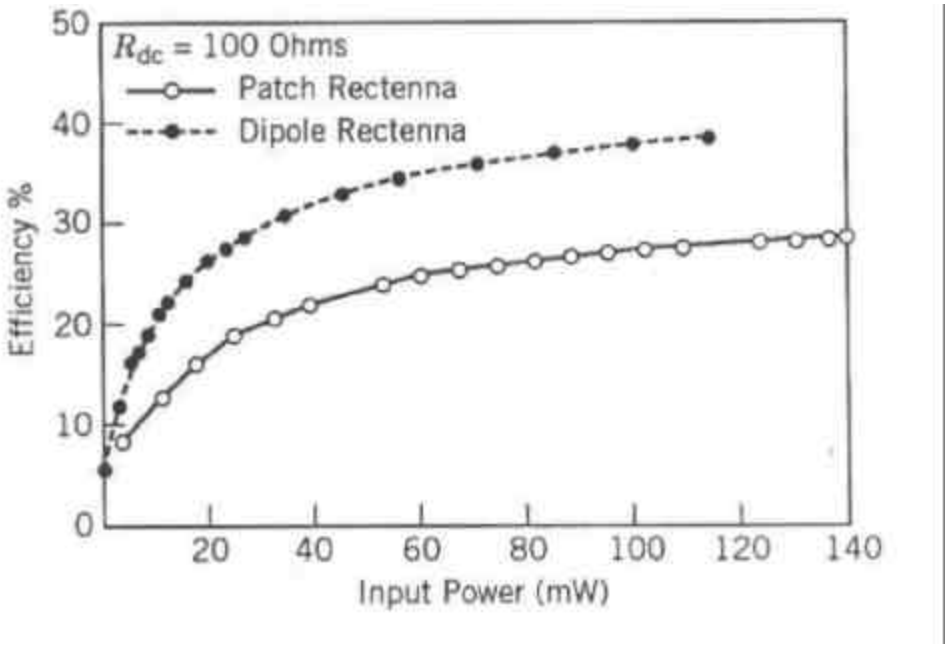
Kai Chang, et.al., IEEE-MTT, 1992

RECTENNA MEASURED EFFICIENCY

Frequency = 35 GHz

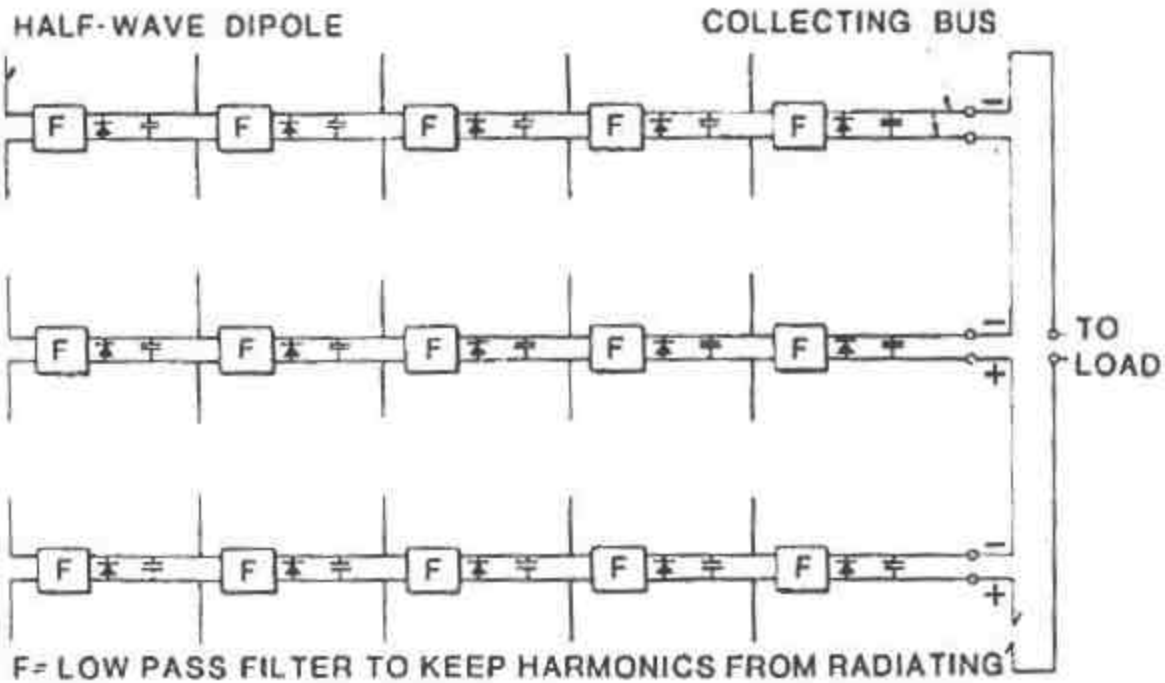
Simulated Array Result

Dipole on 1-mil-thick Kapton



Kai Chang, et.al. IEEE MTT, 1992

Rectenna Array



Note: Rectenna Elements Are Isolated by the Filter, Detector

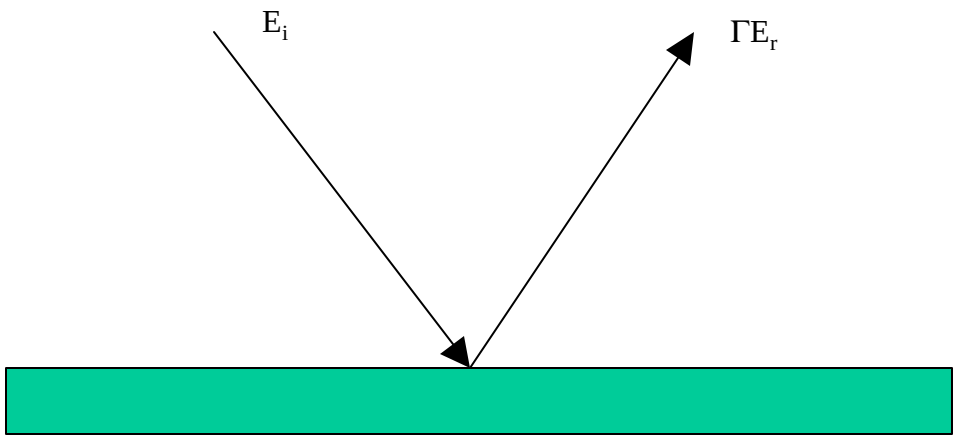
W. C. Brown, et.al, IEEE, 1992

Rectenna Configuration

- Claimed Conversion Efficiency up to 85%
- Individual Dipoles Integrated with:
  - Rectifying Element
  - Impedance Matching Network
  - Low Pass Filter
  - Usually on a Thin Film
- Problems With the Thin Film:
  - Mechanical Strength
  - Electromagnetic Wave may Penetrate Which Limits Efficiency
- Problems with Using a Thick Film:
  - Surface Wave may Reduce Efficiency
  - Narrow Frequency Band
  - Reduction of acceptance Angle
  - Heavy
  - Probably Opaque to Visible Light

Required Electromagnetic Properties

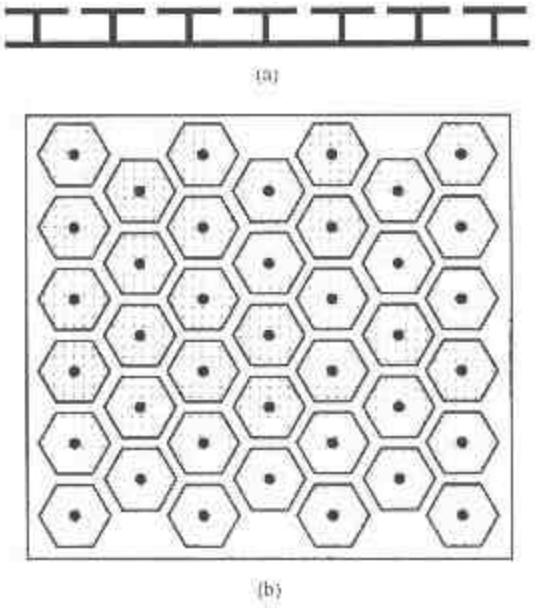
- High Input Impedance over Wide Acceptance Angle

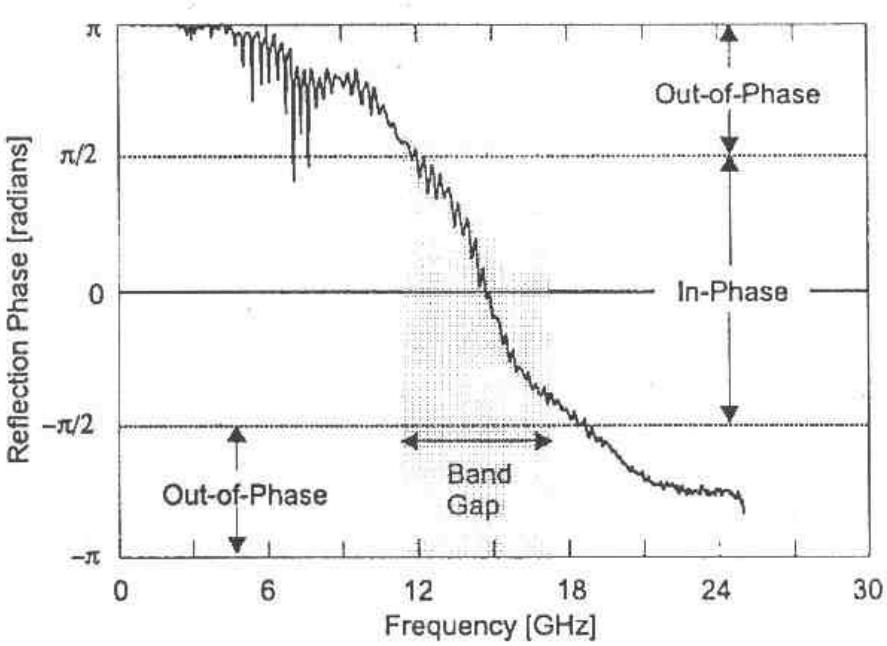


For a Linear Antenna (Dipole)

$$V = \int E_i (1 + \Gamma) \, dl$$

Example of High Impedance Surface

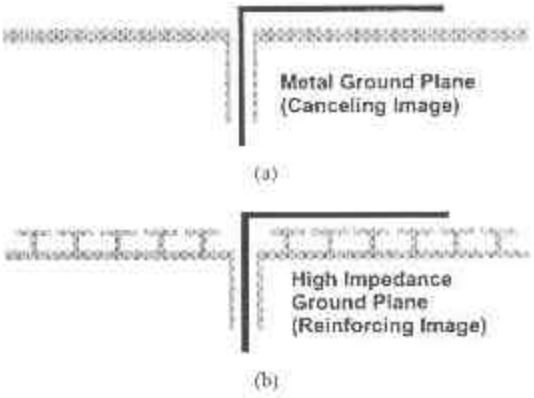


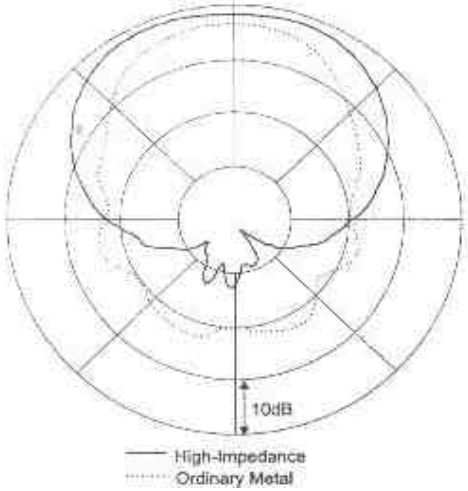


In the Band Gap, the Reflection Phase is at or near zero

Yablonovitch, et.al., IEEE-MTT, 1999

Example of Improvement





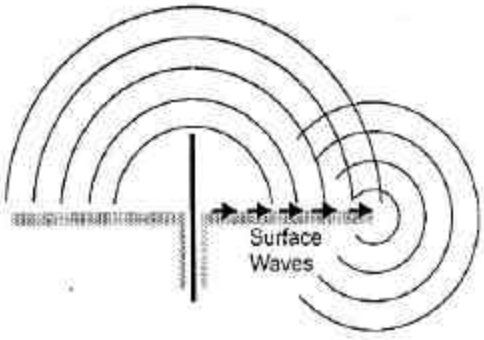
Normalized for Equal Input Power

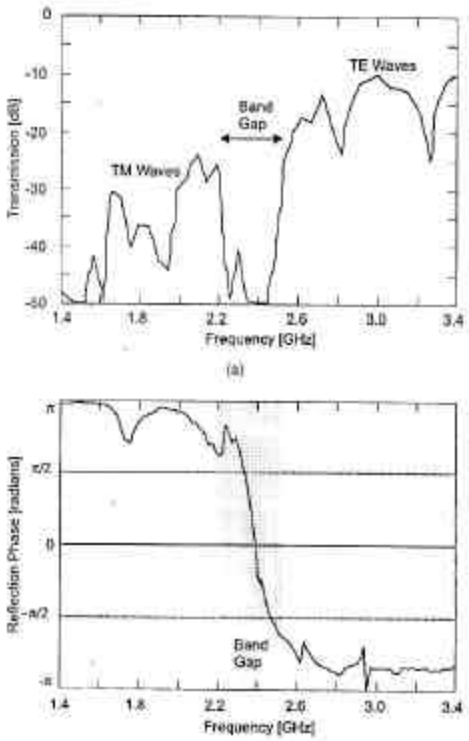
Gain Increases by about 3dB

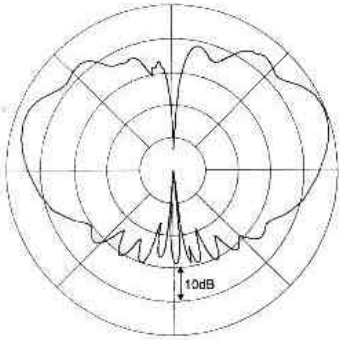
Surface waves are suppressed

Yablonovitch, et.al., IEEE-MTT, 1999

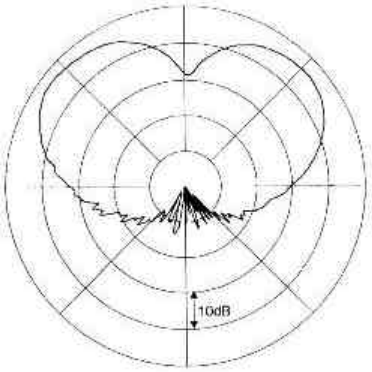
Effect of Surface Waves







With Surface Waves



Surface Waves Suppressed

What Is Required

- Material that will Improve overall efficiency with Minimum Environmental Impact

- **High Impedance for Microwave Frequency**
- **Transparent to Optical Energy**
  - Dual Use of Collecting Area (possibly 100's Km^2)
  - The Collecting Area May be Used for Agriculture
  - Other Uses?
- Will not Impede Weather

- Long Life Under Adverse Conditions
- Strong, Light Weight
- Low cost